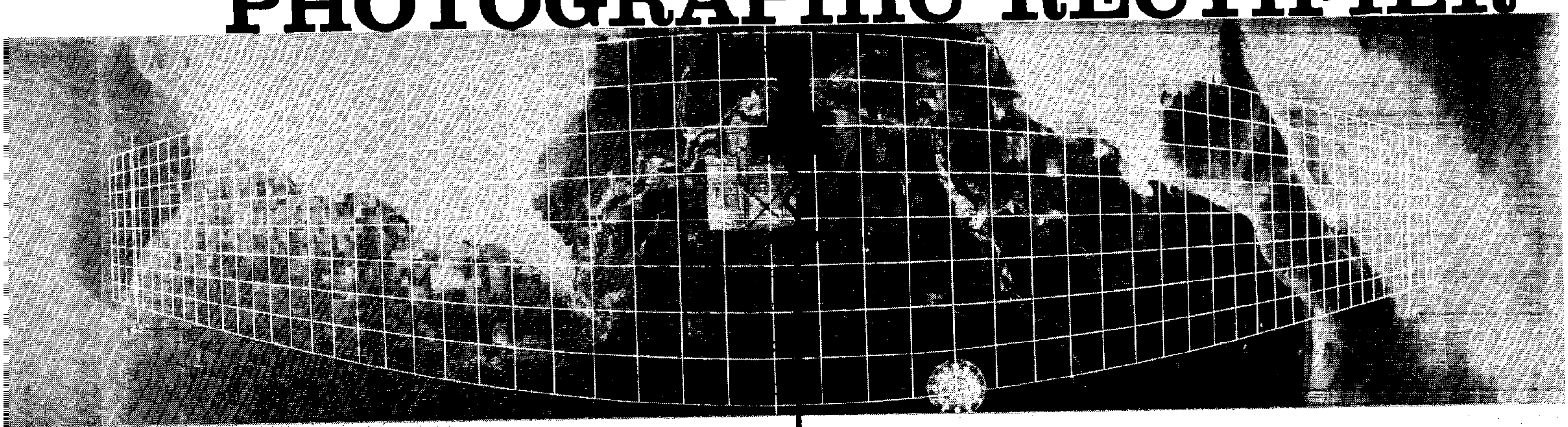
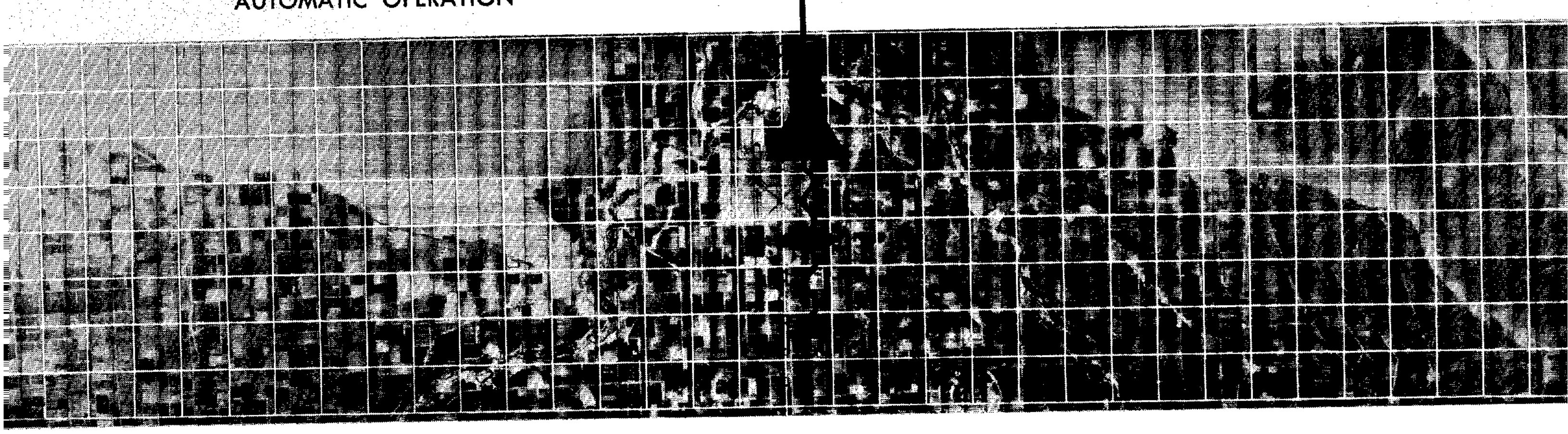
# THE H-229 PHOTOGRAPHIC RECTIFIER



[redacted]

**Featuring . . .**

EXCEPTIONAL FLEXIBILITY
HIGH RESOLUTION
AUTOMATIC OPERATION





ANOTHER OUTSTANDING ACHIEVEMENT BY

# THE WHATS, WHYS, AND HOWS OF PHOTO RECTIFICATION

**WHAT is photo rectification?.....** Rectification is a process whereby a geometrically distorted image is transformed into a true scale photographic reproduction. In the past, limited rectification was accomplished during the projection printing process. Using this technique, the average scale can be corrected by changing the enlargement factor and the effects of lesser degrees of camera tilt and distortion can be removed by tilting the lens or easel. This type of rectification is usually accomplished with photos which have been taken at relatively low altitudes and from near-vertical positions. Photos of this type present relatively small amounts of distortion for the rectification process to contend with.

**WHAT of tomorrow's needs?......** The Space Age has brought with it a requirement for many different types of higher flying, longer range vehicles. The advent of this type of conveyance has brought with it new photographic challenges which must be dealt with by the photographic scientist and engineer. The problem of rendering a high-oblique, a panoramic, or an extremely high-altitude photograph interpretable has presented stumbling blocks such as curvature of the earth and problems caused by elements of the camera system....lenses, mirrors, air refraction, etc....all of which contribute to greater amounts of distortion in the final print. It is

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with pride that [redacted] announces its new H-229 Photographic Rectifier, an outstanding electronic achievement, which will provide a solution for these problems.

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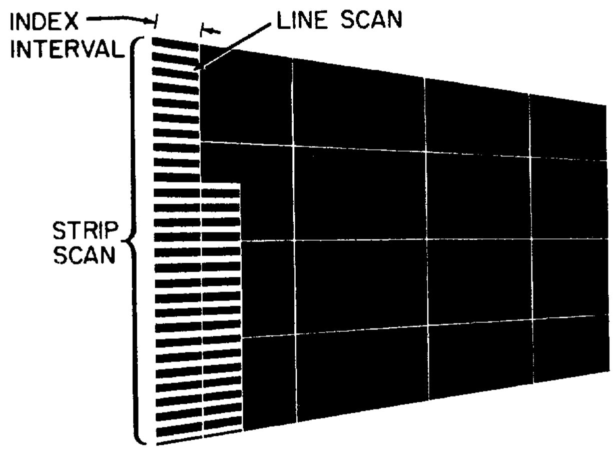
**WHY is photo rectification important today?.....** The answer to this question lies in the fact that through rectification, aerial photographs can be reduced to a common scale and coordinate system for use in mapping and intelligence data gathering. [redacted] new H-229, which is available today, is actually a versatile image transformer and, therefore, through the use of suitable punched tape programs and auxiliary circuits, it can effect any transformation which can be programmed mathematically. Such transformations might include the conversion of existing photographs to simulate photography from new camera systems, the conversion of maps from one type of projection to another, the projection of distorted photography for flight simulators, and the transformation of drawings to different coordinate systems, as well as the removal of distortion from photography.

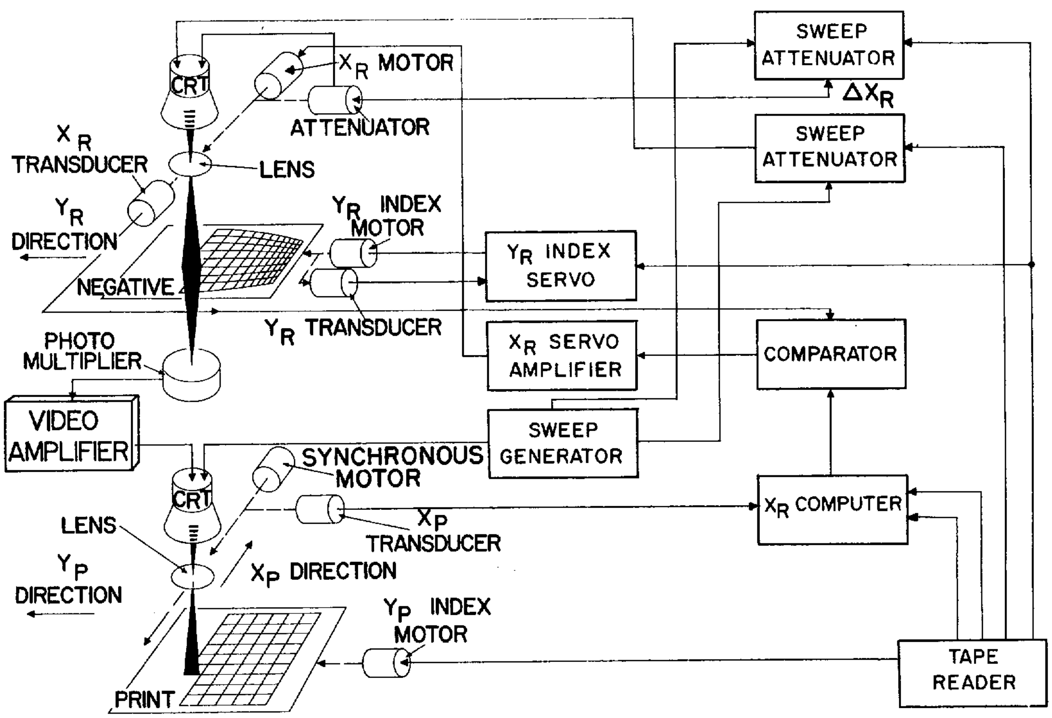
**HOW is this new concept of rectification accomplished?**.................. Basically, the system scans a distorted aerial photograph, converts the image to usable electrical signals, supplies additional transformation data, effects the transformation, and subsequently prints a rectified reproduction of the original photo. The desired geometrical transformation is accomplished by controlling the relative amplitude and orientation of elemental line scans, as well as the relative velocity and placement of strip scans.




Advanced cathode-ray scanning tubes and projection lenses are employed to obtain high resolution. Precision lead screws are utilized for mechanical scanning and film indexing in order to provide excellent image placement accuracy. Reading and printing scans are synchronized by a common clock signal, and the relative scanning patterns are determined by a punched tape program. The numerical control employed is similar to that used for automatic contour milling.

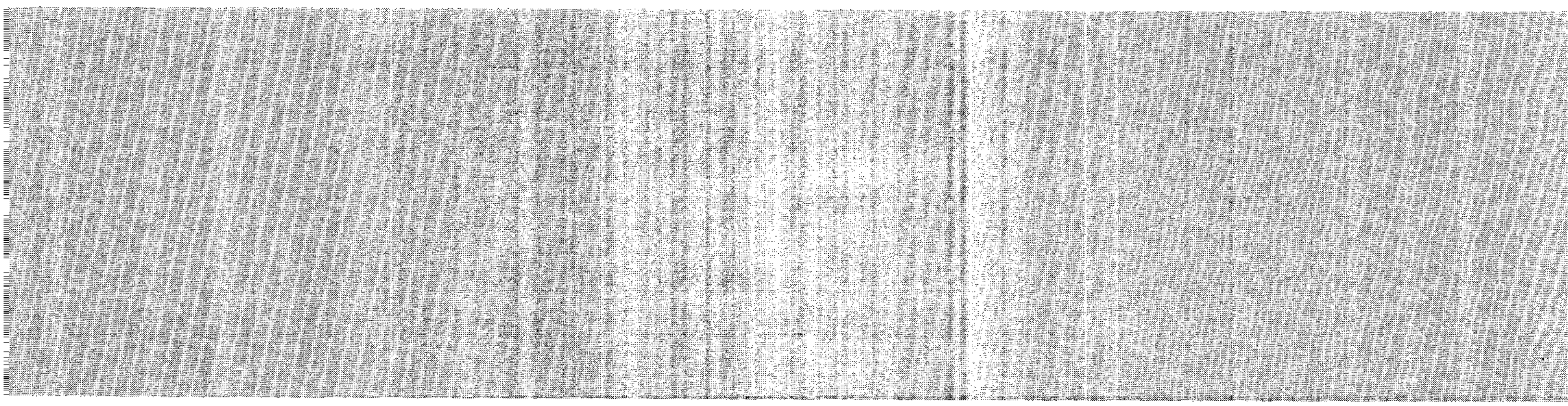
Punched tape programs for different transformations can be produced quickly using any adequate computer facility. Once a negative has been set up in the reading platen, the entire rectification process becomes completely automatic.

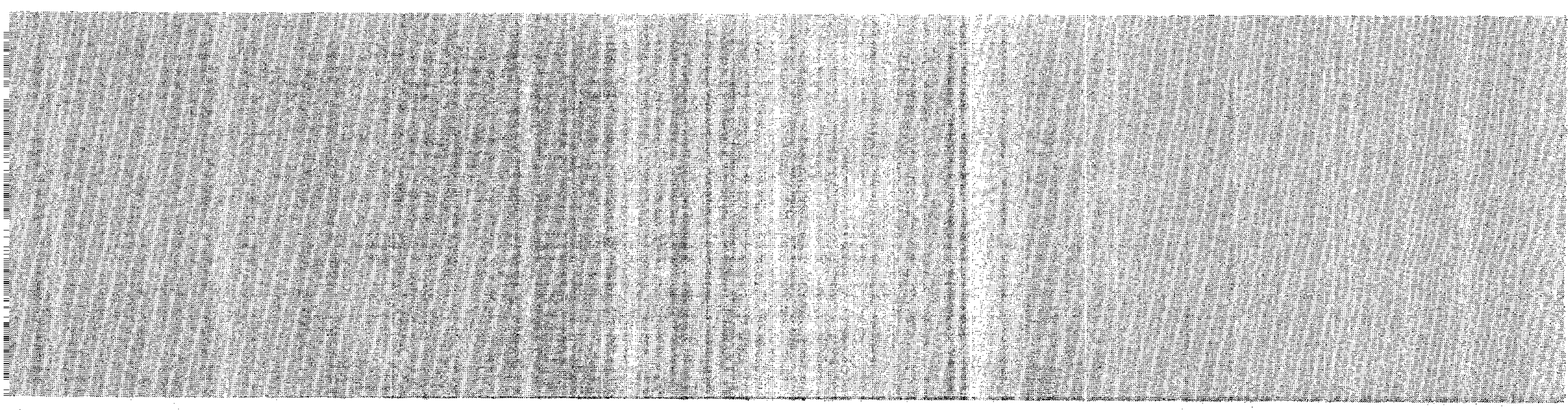
The H-229 Photographic Rectifier's exceptional flexibility permits its use in many fields. However, it will probably find its most important use in the field of aerial reconnaissance.



# TECHNICAL DATA

| | |
|---|---|
| System Resolution | 40 lines/mm for 9-1/2 inch film<br>50 lines/mm for 70mm film |
| Film Size Handled | Up to 9-1/2 inch film, any length |
| Magnification | 1:1 to 4:1 |
| Rectification Time (Panoramic Photograph) | 25 minutes, 70mm film at 50 lines/mm<br>25 minutes, 9-1/2 inch film at 40 lines/mm<br>15 minutes, 70mm film at 25 lines/mm<br>15 minutes, 9-1/2 inch film at 20 lines/mm |
| Cumulative Placement Errors | Maximum, 0.116%<br>Expected, 0.075% |
| Video Frequency | 2 mc |
| Computer Clock Frequency | 5 mc |
| Scan Spot Size at Negative | 0.0003 inch, approx. 4000 TV lines/inch or 80 lines/mm |
| Reader Lens Positioning Error | Less than 0.001 inch |
| Indexing Accuracy | 0.001 inch |







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# PHOTOGRAPHIC RECTIFICATION BY IMAGE SCANNING

[redacted]

## Introduction

Rectification is a process whereby a geometrically distorted image on an aerial photograph is transformed into a constant scale reproduction of the original subject matter.

For aerial surveying, the ideal photograph is a true vertical view; all objects at the ground datum plane appear at the same scale. Aircraft motion causes the majority of camera views to be slightly tilted. For many years, the photogrammetrist has removed the tilt effect during projection printing. The printer lens plane and print easel are tilted to compensate for image scale variation. This is illustrated in Figure 1 where the grid in the negative plane indicates the effect of camera tilt on a photograph of a rectangular grid.

Today, photo reconnaissance imposes additional requirements in image rectification. This arises because photographs obtained by the military are not, for the most part, vertical, but are more likely to be of the panoramic, high-oblique, or extremely high-altitude type. This type of photograph requires extensive rectification in order to transform it into a constant scale, which is mandatory for intelligence data gathering and the making of mosaic maps of enemy terrain. The conventional projection rectifier has not proven satisfactory for the large variety of image transformations often required by the military and, therefore, considerable effort has been applied to newer methods. The rectification of panoramic, high-oblique, and extremely high-altitude photography acquired with several types of cameras has become a pressing requirement in reconnaissance today.

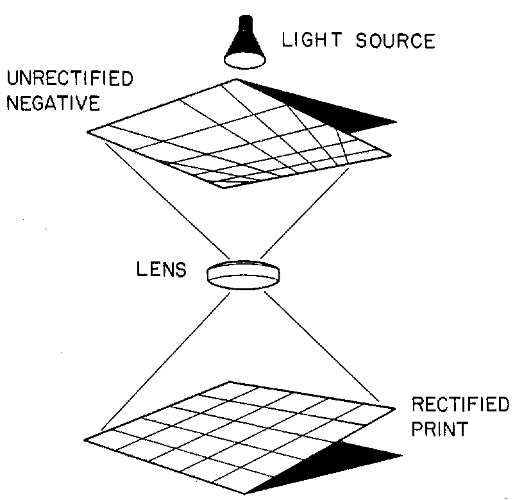


**Figure 1. Optical Rectifier-Printer**



[redacted] has designed and constructed an engineering model of an image scanning photographic rectifier. This design was directed toward increasing the range of rectifying transformation while preserving image detail and placement accuracy. The operation of this equipment is illustrated in Figure 2.

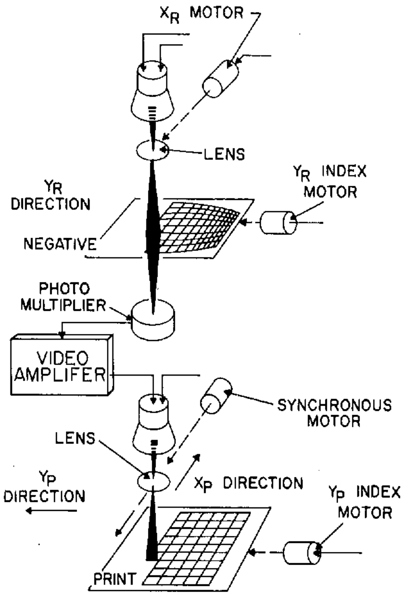


**Figure 2. Photo Rectification by Scanning**

A distorted aerial photo is scanned to convert the image to a video signal. The image is transformed, reproduced and printed. The relation between reading and printing scan patterns determines the transformation in image geometry. The grid in the negative or reading plane shown in Figure 2 illustrates a panoramic photograph of a rectangular grid. The engineering model has been built to prove the feasibility of this method of rectification. The principal features of this equipment are versatility and high resolution. The machine is controlled by a punched tape that has been programmed to command the relative scanning pattern. The resolution of the printed image (relative to the scale of the original negative) is 30 photographic lines per millimeter.

## Image Transformation by Scanning

Kinescope displays are often distorted for special effect by varying the relative pickup and display scanning patterns. With a fixed pattern display, the scanning camera can cause the image to be rotated and stretched many ways. In adapting this technique to rectification, a fixed display pattern is also used. The scheme used for displaying and printing the image has been selected to meet preliminary photographic requirements.

The rectified print is exposed in a succession of narrow contiguous strips. Each strip is of equal width and length and is composed of a raster of line scans which are developed into a strip by optically and mechanically translating the line scan image from the printing kinescope (refer to Figure 2). The flying spot display on a cathode ray tube is optically reduced to improve the resolution of the image. To insure that exposure time is constant for printing film, scan velocities are fixed throughout a rectification. The reading scan pattern is developed to perform a given geometric transformation. It can be seen that when a constant scale line image is printed by a fixed velocity spot scan, the pickup sweep is not linear for a variable scale negative image. To use linear sweeps for reading, line scans are kept short (less than 1/8 inch on the negative) to result in negligible error from variation in negative scale.

The relative printing and reading scan patterns for the rectification of an oblique photograph are illustrated in Figure 3. The keystoned grid illustrates a rectangular grid transformed by oblique photography.

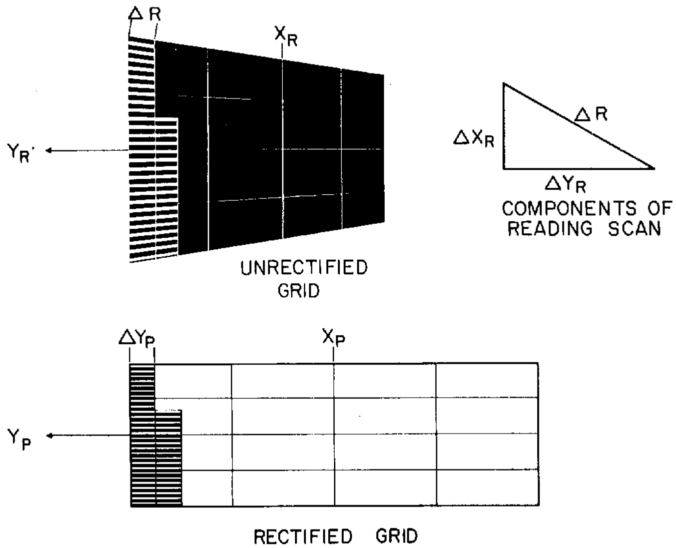


**Figure 3. Scanning Pattern for an Oblique Photograph**

In Figure 3, the Yr axis is selected as the principal line of the negative image. The Xr axis is a perpendicular coordinate through the principal point of the photograph. A characteristic of oblique and panoramic photography is that straight lines (Yr = constant) transform into straight lines (Yp = constant). (See Appendix for more complete discussion of panoramic rectification. For information on the geometry of rectification see Reference 1.)

To perform a rectification, the line scan (Δ R) amplitude and direction and the lens scan position (Xr and Yr) must be controlled by the following printing scan constants:

| | | |
|---|---|---|
| ΔYp = Ypn - Yp(n-1) | = | line scan length |
| Yp0, Yp1, Yp2, Yp(n-1) | = | position of center line of each strip scan |
| X0 | = | starting position of strip scan |
| Xp1, Xp2, Xp3, Xp(n-1) | = | evenly spaced scan positions for checking reading strip scan position. |

The reading line scan Δ R is produced by adding its components Δ Yr and Δ Xr in the flying spot scanner deflection yoke. For oblique and panoramic rectifying transformations, it can be shown that Δ Yr is constant for any strip scan position (Yp0, Yp1, etc.) and that Δ Xr = K Xp where K is a constant determined for any strip scan position (Yp0, Yp1, etc.). The sweep amplitude Δ Xr varies continuously as an analog of lens position (X).

The position of the strip scan (reading lens) can be computed by integrating the scan rate $\dot{X}r$ from a previously known position. (The ratio of scan velocities $\frac{\dot{X}p}{\dot{X}r}$ is constant for any strip scan for rectification of oblique or panoramic images.) The accuracy of the computed position can be improved if it is checked at precomputed points Xr0, Xr1, etc. when the printing lens is at positions Xp0, Xp1, etc., respectively.

The position of the negative platen (Yr0, Yr1, Yr2 ....) is dependent only upon print table position (Yp0, Yp1, Yp2, etc.). These positions can be precomputed to command the position of the negative for successive strip scans. The

accurate computation and control of scans has indicated the use of a numerical control system similar to that employed for automatic contour milling.

## Design

A functional diagram of the photo rectifier is shown in Figure 4. The photo transmission system consists of reading and printing flying spot scanners and the video link. The scanning mechanism includes the synchronized electronic sweeps and the precision lens drive and film indexing system. The programming system continuously computes and commands the position and velocity of scanning from numerical data on punched tape.

## Photo Transmission System

The photo transmission system is basically a closed-loop television system. The negative is read by a flying spot scanner (using a cathode ray tube and a photomultiplier). A projection quality cathode ray tube is used for reading. The video signal (250 KC bandwidth) is displayed and the display is optically reduced on the photographic print. Less resolution is required for printing, since the minimum negative scale enlargement is 4X. (A 70 mm negative is enlarged to a positive transparency on 9-1/2 inch film.)



The principal consideration in the photo transmission design was good resolution with a reasonable exposure range. The exposure range (or number of gray levels) is limited by the signal-to-noise ratio of the video signal and the printing C. R. T. The reading system employs a high quality flying spot scanner [redacted] K1725-P16) with a matching photomultiplier [redacted] 6363-511).



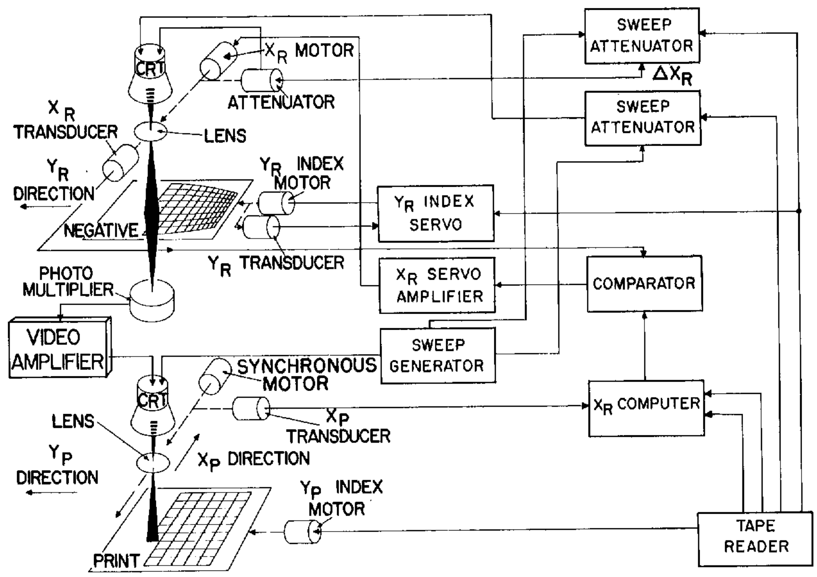


Figure 4. Functional Diagram, H-229 Scanning Section

To improve the resolution, the cathode ray tube trace was optically reduced 4X. The reduction in light gathered reduced the signal output of the photo multiplier. Adequate improvement in light was achieved through the use of a large aperture projection lens [redacted] f/2) and by a scanning raster (as opposed to a line trace) on the cathode ray tube. The raster scan reduced phosphor fatigue (from repeated scans) and permitted increased beam current. Since the vertical or strip scan is primarily made by translating the lens, the lens position and velocity were compensated to correct for the raster scan.

Special attention was also given to filtering and the regulation of power supplies.

## Scanning Mechanism

The method of scanning is shown in Figure 4. Cathode ray tube displays are optically projected for line scanning; The projection lens is translated to produce strip scans; and film is moved to cover a sequence of adjacent contiguous strip images.

Line scans are generated from a common sweep voltage generator. The printing kinescope sweep is fixed in amplitude and orientation. The linear reading scan is varied in amplitude and rotation by driving horizontal and vertical deflection coils with the computed sweep signal components. This method of sweep rotation simplifies the reading sweep amplitude computation and also causes negligible drift in the sweep center position.

Strip scans are produced by moving the projection lens carriage on a precision lead screw and ways. Precision was required for accuracy of position and also to maintain focus. To minimize the velocity error of the scan servomechanism, nuts riding on the lead screw were threaded over a $120^{o}$ arc to reduce friction.

Lead screw drives were also used to accurately position the reading table (negative) after each strip scan.

## Numerical Control

The method of numerical control is indicated in Figure 4. Deflection signals at the pickup cathode ray tube are attenuated by tape controlled attenuators consisting of relays and precision resistors. One deflection component is also attenuated as an analog of lens position.

The reading platen is positioned by a servo system. This is accomplished by comparing its numerically encoded position with program tape commands.

To perform the image rectification, it is necessary to control the reading lens position as a function of the printer lens position at any instant in time. Figure 5 shows how the desired reading lens position is continuously computed and registered. At the instant the printing lens reaches a starting or reference position, the desired numerical reading lens position (for a specific scan) is read from the tape and registered in the reference position counter.

A position pulse generator emits a pulse for a minute increment of lens displacement. A count of these position pulses is a precise indication of displacement and the pulse rate is analogous to the lens velocity.

By programming the ratio of strip scan velocity, a pulse rate can be produced analogous to the reading scan velocity. This is accomplished by multiplying the pulse frequency and dividing it with a programmed counter. After the initial lens position is registered by a counter, each pulse of ready velocity analog is added in the counter. The counter continuously registers the computed numerical reading scan position.

Only a minute error can result from the method of computing pulse frequency, since only a finite number of velocity ratios can be numerically programmed. In order to prevent the accumulation of a significant error, the registered position in the counter is corrected from the punched tape data at frequent intervals (better than 8 times per inch of reader lens travel).

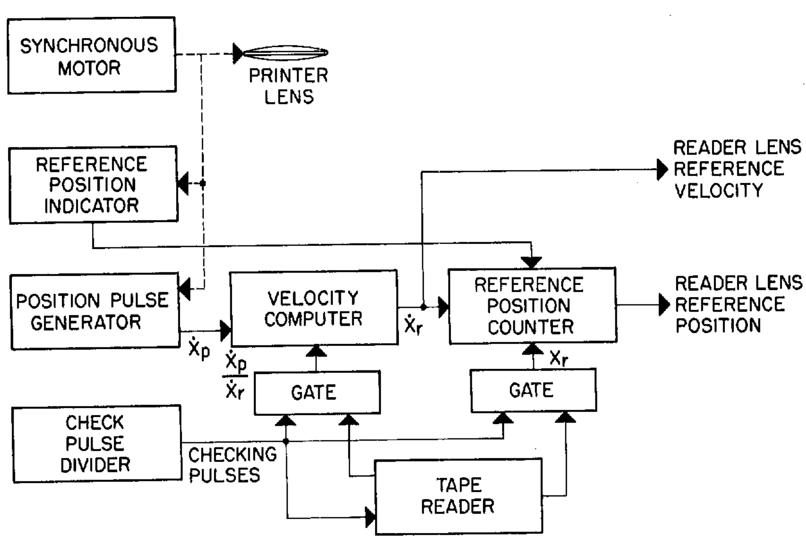


Figure 5. Scan Position and Velocity Computer

The reading lens position is controlled by the reference counter indication. Figure 6 shows the lens servomechanism. The lens position is numerically encoded by integrating its pulse rate velocity analog from an initial reference position. The position is registered by a true position counter. After comparing the commanded and controlled positions, the numerical error is converted to a voltage analog. The lens velocity is determined by the computed velocity analog (with a velocity servo loop) and the error signal provides position control. Acceleration and rate damping enable the use of a stable high servo gain with minimum control error.

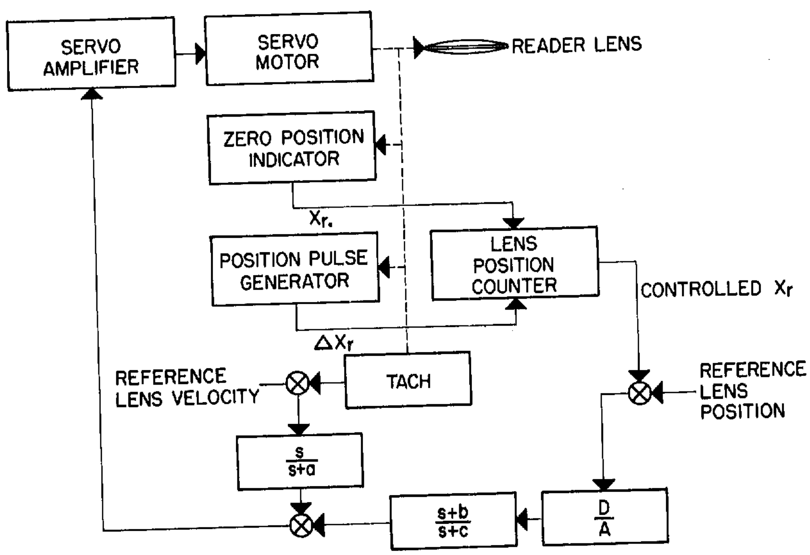


Figure 6. Lens Scan Servomechanism

## Performance

The performance of the photo rectifier model has been measured by its photographic results. The principal result was the rectification of panoramic photographs. An aerial photograph from a panoramic camera is shown in Figure 7a. The rectified image is shown in Figure 7b. The original rectification was reduced 4X before making the half tone print shown in Figure 7b. The overlaid grids indicate the nature of the rectifying transformation.

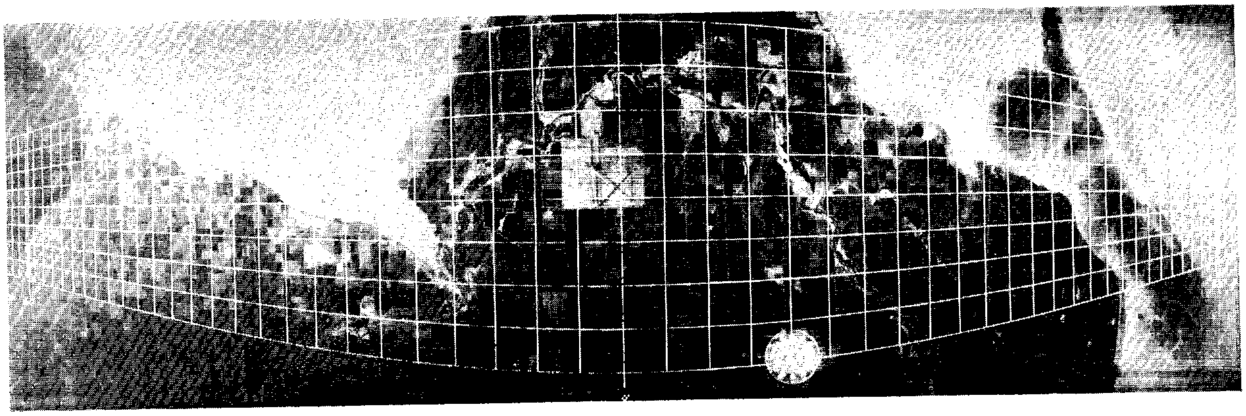

Figure 7(a). Results - Before Rectification (1:1)

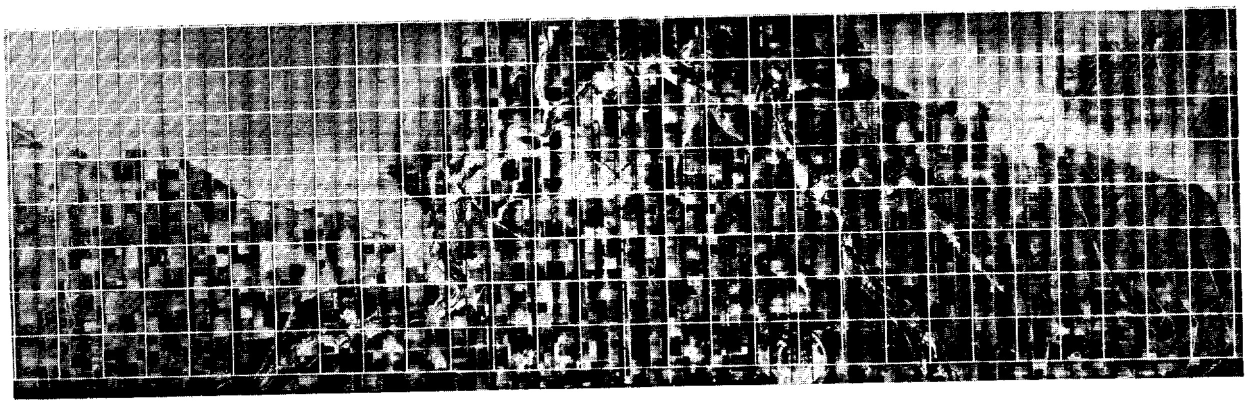

Figure 7(b). Results - After Rectification

<u>Resolution</u>

Overall system resolution was measured by placing a Standard Air Force Resolution Chart in the negative film platen and printing it 4X enlarged. The result was further enlarged 5X in a photo enlarger and shown in Figure 8. The 16 and 32 line per millimeter targets are circled showing they were resolved.

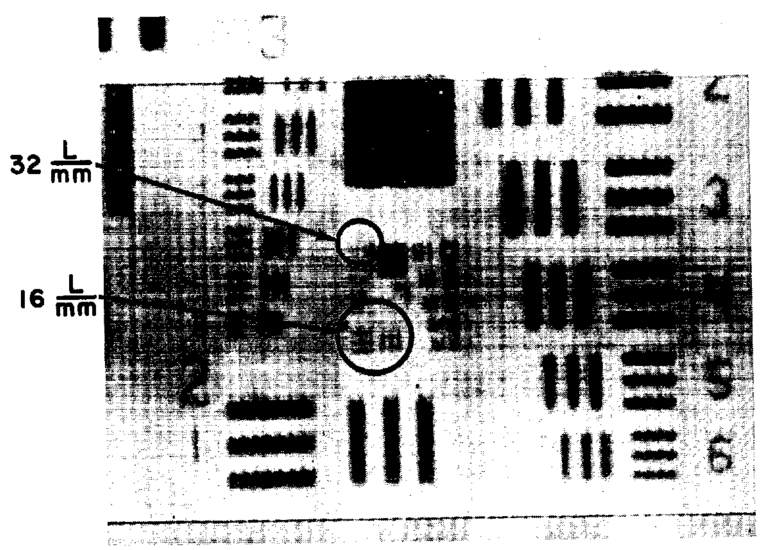


Figure 8. Resolution Chart

The reading resolution was determined by measuring the video signal rise time when scanning a sharp edge in the negative plane (a

test reticule). This measurement showed that 2000 T. V. lines per inch were well resolved, which results in 40 photographic lines per millimeter (accepting 2 T. V. lines per 1 photographic line). (The method of measuring reading resolution was taken from Reference 2.)

The printing system resolution was measured by generating a dot pattern on the printing kinescope. Better than 20 photo lines per millimeter were resolved on the printed pattern. This corresponded to 80 lines per millimeter with respect to the negative scale after 4X enlargement. Photographs were enlarged 4X (at the nadir point) as well as being rectified. This substantially reduced degradation of image detail by the limitation in printing resolution.

Exposure Range

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The use of optical reduction reduces the effective illumination from the cathode ray tubes. However, for printing, the light available was adequate to fully expose with the ASA 80 film used. ([redacted] K1405-P11 C. R. T. is used with an f/4.5 projection lens for printing.)

The dynamic range of exposure was better than 20:1, that is, the variation in the density of the rectified image was less than 1-1/2 log units. The principal exposure range limitation is the signal to noise ratio at the photomultiplier output.

Other Photographic Characteristics

Overlapping scans were used to minimize evidence of scanning lines in the print. After 16X enlargement, evidence of scanning can be detected. Referring to Figures 7(a) and 7(b), lines appearing in this photograph were caused by a 60 CPS interference with the magnetic deflection field.

From Figure 7(b), the effect of strip scanning is quite apparent. The strip effect is accented in this figure by improper shading adjustment and also by an inadequate A. G. C. circuit. Nevertheless, lines joining the image do detract from the appearance. This is justified for reconnaissance purposes where appearance is secondary and the image transformation cannot otherwise be accomplished with adequate resolution or placement accuracy. No attempts were made to soften the strip effect by comb mattes or variable density edges.

Placement Accuracy

The placement accuracy desired for this equipment is the location of any image element within 0.010 inch from its ideal position, determined with respect to the image element position on the negative and the rectifying transformation. The engineering model fulfilled these specifications.

The placement accuracy achieved is attributed to precision mechanisms and numerical control. Line scans produced by a cathode ray tube were short; errors occurring from non-linearity in sweeps (less than 1%) accounted for a minute error.

## Speed of Operation

The rectification of an entire panoramic photograph such as shown in Figure 7(b) requires 40 minutes. Excepting scan retrace time, which requires almost 50% of the total time, the time required is limited by the resolution, format size (70 mm x 7 inches), and video bandwidth (250 KC) used. A significant reduction in scanning time will be limited by the accuracy required and the clock frequency used in numerical contro. At present, the computing clock frequency is 1 MC/s and the computation error is less than 0.00025 inch.

## General Considerations

The scanning method used here may be extended to more difficult transformations, such as earth's curvature corrections. This will require more complex scans; non-linear scans will be required. The numerical control system employed can be used for precise programming of non-linear motion.

The principal restraint to higher resolution in scanning rectifiers or photo transmission systems in general is available light from small flying apertures in reading scanners. The achievement of a resolution of 30 photographic lines per millimeter is not represented as a limitation, but it required some reduction in the range of exposure (to 20 or 30 to 1).



The engineering model of the rectifier described in this paper was based, almost entirely, upon concepts developed by [redacted] U. S. N.

Reference 1. Manual of Photogrammetry, Chapter VI, American Society of Photogrammetry.



Reference 2. Cathode Ray Tube Recording Symposium, Jan. 13-14, 1959, "Methods of Determining Spot Size", [redacted]

Reference 3. "Emulsion Sensitivity for the Photography of Cathode Ray Tubes" by R. W. Tyler and F. C. Eisen, Journal of Society of Motion Picture and Television Engineers, April, 1959.



Reference 4. "System Design of Flying Spot Store", [redacted] Technical Journal, March, 1959.

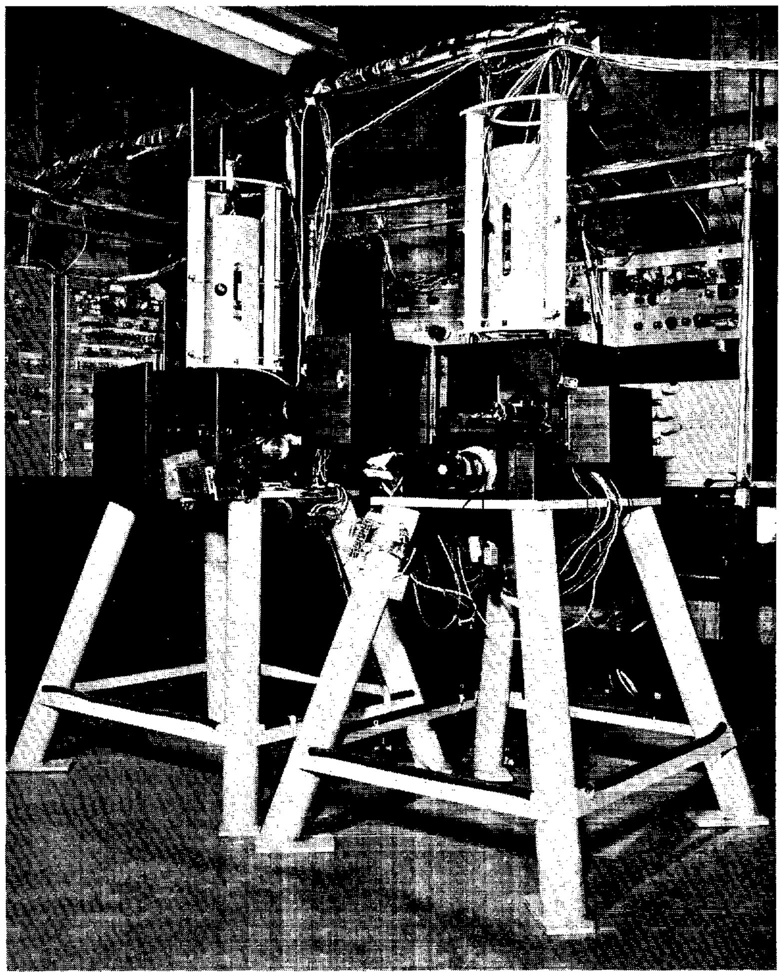

Figure 9. Engineering Model of H-229 Photo Rectifier

APPENDIX

## Programming A Panoramic Rectification

When a panoramic negative is lined up in the rectifier reading carriage, the machine's Yr axis is the principal line of the photograph and the Xr axis intersects the nadir point of the photograph. Then the rectifying transformation is expressed in the equations (1) and (2). This transformation is indicated in the grid image relationship shown in Figure 2.

$$\frac{Xr}{f} = \frac{\frac{Xp}{h}}{\sqrt{1 + \left(\frac{Yp}{h}\right)^2}} \qquad (1)$$

$$\frac{Yr}{f} = \tan^{-1}\left(\frac{Yp}{h}\right) \qquad (2)$$

where Xp and Yp are axes of the machine print plane,

f is camera focal length.

h is relative altitude ($\frac{h}{f}$ is the scale enlargement at the nadir point of the rectified print).

Printing scan constants are:

$\Delta Yp = Ypn - Yp(n-1) =$ constant

Yp0, Yp1, Yp2 = position of center of each strip scan

Xp0, Xp1, Xp2 = position of center of scan start and each check point

$Xpn - Xp(n-1) =$ constant

To program reading scans, the variables to be precomputed are:

$\Delta Yr$ for Yp0, Yp1, Yp2, etc.

$\frac{\Delta Xr}{Xp}$ for Yp0, Yp1, Yp2, etc.

Yr for Yp0, Yp1, Yp2, etc. .

$\frac{Xp}{Xr}$ for Yp0, Yp1, Yp2, etc.

The sweep amplitude $\Delta Yr$ can be determined by differentiating equation (2).

$$Yr = \frac{f}{h} \left( \frac{1}{1 + (\frac{Yp}{h})^2} \right) \quad \Delta Yp \qquad (3)$$

It can be seen that $\Delta Yr$ is independent of Xr and is constant for any strip scan. The value of $\Delta Yr$ can be computed and stored for values Yp = Yp0, Yp1, etc.

The sweep amplitude $\Delta Xr$ can be computed by differentiating equation (1).

$$Xr = -Xp \left( \frac{f\,Yp}{(h^2 + Yp^2)^{3/2}} \right) \quad \Delta Yp \qquad (4)$$

Amplitude Xr is jointly determined by printing lens position Xp and a function of print table position Yp0, Yp1, Yp2, etc.

The ratio scan velocities $\frac{\dot{X}p}{\dot{X}r}$ results from differentiating equation (1) with respect to time.

$$\frac{\dot{X}p}{\dot{X}r} = \frac{h}{f} \sqrt{1 + (\frac{Yp}{h})^2} \qquad (5)$$

The relative strip scan velocity is constant for any strip scan. The reading lens velocity ($\dot{X}r$) can be computed as a function of the print table position (Yp) and is analogous to the print scan velocity ($\dot{X}p$).

Check positions Xr0, Xr1, etc. can be precomputed for each scan (from equation (1)) and used to correct position at time Xp = Xp0, Xp1, etc.



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# ENLARGED AERIAL PHOTO

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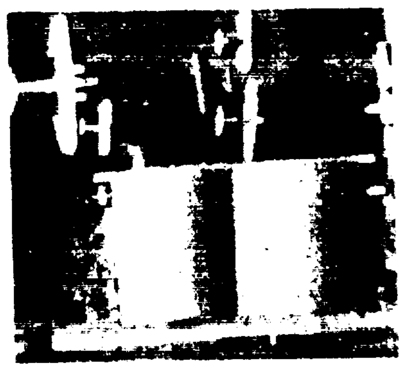

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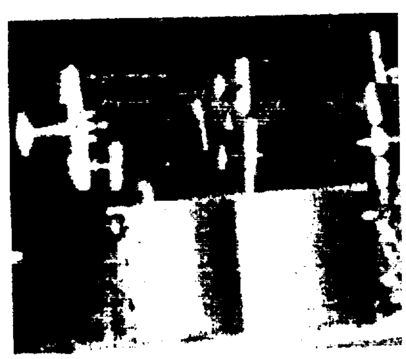

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